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Diversification of Agricultural Production in China: Economic Rationality of Crop Choice under the Producer Subsidy Program

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Dietary habits of Chinese people have transformed drastically over recent years due to rapid economic and income growth, urbanization, and globalization. In response, farmers motivated to enhance their incomes should shift their product mixes to meet these new preferences. If, however, the government prioritizes self-sufficiency for staple foods, farmers' choices will diverge from the income-enhancing outcome. This study thus examines farmer's crop choice rationality in Chinese agriculture via estimation of a stochastic frontier output distance function. The estimated results for allocative efficiencies offer unambiguous evidence that grains excessively are produced relative to vegetables and fruits, a tendency that was particularly noticeable during the time of the Producer Subsidy Program. This program also had a distorting effect on farmers' abilities to make technically efficient choices. These findings lend strong support to the assertion that China's policy goal of grain self-sufficiency is to the detriment of agricultural production in terms of technical and allocative efficiencies.

Key words: Chinese agriculture, production diversification, food self-sufficiency, output distance function

1. Introduction

The Agricultural Basic Act, enacted in Japan in 1961, set a policy agenda of altering the course of the Japanese farm sector over the following several decades (National Chamber of Agriculture, 1961). One of the most important concepts articulated in the Act is the transformation of the agricultural product mix: Article 2 stipulates that the government should implement appropriate measures to diversify and selectively expand farm production so that the volume of crops with anticipated future domestic demand growth is continually increased. It also opines that the product mix in this way is consistent with pursuing comparative advantage in Japanese agriculture. At the time of the Act, many senior officials and agricultural economists predicted that future economic growth would result in dynamic changes in the dietary habits of Japanese citizens (Tsuchiya, 1997). Not surprisingly, their prediction was reasonably accurate: the per capita consumption of rice and starchy roots decreased by half from the 1960s to 2000s, whereas that of fresh vegetables and fruits, meat, dairy, and eggs increased many-fold over this period.

This is not a phenomenon unique to Japan: in recent years, many Asian countries have followed a similar trajectory in eating habits, shifting away from the traditional dominance of rice towards Western food types. This stems mainly from rapid economic and income growth, urbanization, and globalization, as described by Pingali (2006). In combination with these factors, modernization of the retail food sector and vertical integration of food supply accelerate these shifts. As a result, diversification and selective

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expansion of farm products are policy challenges relevant to both Japan a half-century ago and other Asian countries in the present-day. It is important, however, that governments need not rely on administrative controls to realize this policy objective because market mechanisms can also play substitutionary roles. To the extent that an increase in demand for certain produces with greater income elasticity, accompanied by economic growth, raises the prices for producers of these crops, farmers motivated to enhance their income should shift their product mix to favor these more-demanded products (Egaitsu, 1976). In other words, producers' rational crop choice behavior should automatically result in diversification and selective expansion of farm products. However, if government places a high premium on national self-sufficiency in staple foods at the expense of connecting farmers to more lucrative markets, crop choices move away from the income-maximizing portfolios.

China offers an interesting case in this regard. The central government has aimed at food security since the 1960s by promoting provincial-level grain self-sufficiency. This was likely inspired by military concerns, poor transport logistics, and, most importantly, rapid demographic growth that nearly doubled the population between 1949 and 1985 (Christiansen, 2009). In 1995, the central government launched the "rice sack" governors' responsibility system, under which governors assume responsibility for balancing the supply and demand for grain and maintaining a stable staple food market at the provincial level (World Bank, 1997). Furthermore, the medium- to long-term food security plan adopted by the State Council in 2008 advocated national goals of maintaining a 95% self-sufficiency rate for grain and securing farmland for that purpose.[1] However, it is commonly believed that China's comparative advantage in the grain sector is on the verge of being eroded, mainly due to increased opportunity costs of farm labor. Grain production declined for the fifth consecutive year in 2003, which resulted in a self-sufficiency rate below 90% for 2001–2003 (FAOSTAT). Confronted with this situation, the central government introduced the Producer Subsidy Program (PSP) in 2004 in an attempt to boost grain production.

The two policy goals of grain self-sufficiency and diversification of farm products are not necessarily incompatible, but attaining them simultaneously is difficult given the structure of comparative advantage, limited farm production resources, and restricted policy options available to China as a World Trade Organization (WTO) member. As such, this study addresses the impacts of government interventions in food markets on farmers' technical and crop choices in China, with particular consideration of the PSP. To investigate this empirically, we employ a stochastic frontier output distance function (ODF) approach. This methodology not only accommodates multi-input and multi-output production technology but also has the advantage of measuring technical and allocative efficiency scores. The analysis is done using panel data for 30 provinces during the period 1991–2009. Although Brümmer *et al.* (2006) and Carter and Estrin (2001) estimated the efficiency scores of Chinese agriculture via the ODF, no research has yet explored the effects of the PSP on farm management. The present study seeks to fill this knowledge gap by examining economic consequences of government interventions in China's food markets. In contrast to the empirical findings of Huang *et al.* (2011), this study shows that the PSP has a distorting effect on farm production and thereby adversely affects technical and allocative efficiencies.

The remainder of this paper is organized as follows. Section 2 outlines the farm production and agricultural policy development of the past decades. Section 3 contains a brief overview of the stochastic frontier ODF model.[2] In Section 4, we explain the data and processing steps. In Section 5, we present results of estimating the ODF and discuss key factors that influence the technical and allocative efficiency scores. Finally, Section 6 concludes with a brief summary of our results, providing some policy implications.

1) The government set a policy goal of a 95% self-sufficiency rate for grain, but there is no such targeted sufficiency rate for food in general (Ikegami, 2006).

2) This study does not address allocative efficiencies of factor inputs that are examined via an input distance function approach.

2. Farm Production and Agricultural Policy

1) Farm production

In this study, we categorize farm products into three sectors: the first sector is grain for staple foods, consisting of rice, wheat, barley, oats, rye, starchy roots, and other staples (9 items): the second sector is grain for processing and feed, consisting of maize, soybeans, and similar crops (8 items); and the third sector is vegetables (20 items) and fruits (22 items). The China Statistical Yearbook (CSY) reports the production volume of grain as the total sum of production in the first sector, plus maize and soybeans, multiplying starchy root production by 0.2. However, this study does not make such a correction. From the viewpoint of diversification and selective expansion of farm products, we should have included the livestock sector in this analysis. However, it is excluded because we focus exclusively on farm sectors that depend heavily on farmland for production. Since China's livestock production has maintained complete self-sufficiency over recent years, we assume that the expansion of the livestock sector is reflected in growing demand for feed grains. Table 1 summarizes how production volume, the self-sufficiency rate, and the shares of sown areas and farm production value have changed over the past three decades. The self-sufficiency rate in Table 1 is defined as production divided by domestic supply quantity. "Share of sown areas" measures sown areas in each sector divided by the total sown areas; the sum of the three sectors' shares does not reach 100 % because the agricultural commodities included in this study accounted for 95.9% of the total sown area in 2009. In order to compute the share of production value, we draw on data on producer's nominal prices for individual crops, obtained from FAOSTAT.

The production of staple foods increased steadily throughout the 1980s and 1990s but stagnated or declined after reaching a peak of 507 million tons in 1999. The self-sufficiency rate in the first sector has been maintained despite this downward production trend because demand for staple foods has decreased. Production of grain for processing and feed expanded consistently during the period concerned. The reason for the decline in the self-sufficiency rate in the second sector is a considerable increase in demand for eligible oils and livestock feeds.

Table 1. Production by sector

	Grain for staple foods (the first sector)				Grain for processing and feed (the second sector)				Vegetables and fruits (the third sector)			
	Production volume 100 MT	Self-sufficiency rate %	Sown area share %	Production value share %	Production volume 100 MT	Self-sufficiency rate %	Sown area share %	Production value share %	Production volume 100 MT	Self-sufficiency rate %	Sown area share %	Production value share %
1980	3.53	96.1	—	—	0.84	92.5	—	—	0.65	101.3	—	—
1985	3.98	97.6	—	—	0.98	103.6	—	—	1.10	100.7	—	—
1990	4.37	100.5	—	—	1.33	106.5	—	—	1.53	100.7	—	—
1991	4.29	101.5	54.5	50.9	1.37	106.5	28.3	19.1	1.59	100.8	7.9	30.0
1995	4.65	97.3	50.7	47.9	1.57	95.6	31.4	19.4	2.54	100.7	11.8	32.8
2000	4.84	96.0	46.5	38.8	1.58	84.5	32.7	17.3	4.21	100.6	15.5	43.9
2001	4.61	90.6	44.0	32.2	1.67	87.2	33.5	18.7	4.49	100.8	16.3	49.1
2002	4.60	90.4	43.1	29.2	1.75	88.5	33.6	18.7	4.81	101.0	17.1	52.2
2003	4.34	87.4	41.0	31.5	1.67	82.9	34.1	19.8	4.95	101.4	18.0	48.7
2004	4.60	92.9	41.3	35.9	1.89	89.4	34.3	18.0	5.13	101.6	17.8	46.1
2005	4.63	95.5	41.8	35.1	1.96	88.2	34.5	17.0	5.33	101.8	17.9	47.9
2006	4.37	94.5	42.3	30.5	2.06	91.1	34.4	18.0	5.59	101.8	17.6	51.4
2007	4.47	96.8	42.0	26.2	2.05	87.8	34.3	14.3	5.88	102.2	18.1	59.5
2008	4.65	98.8	41.5	25.3	2.25	89.0	35.1	14.4	6.20	102.0	18.3	60.3
2009	4.72	95.7	41.5	25.9	2.22	86.3	35.8	15.2	6.39	101.8	18.6	58.9

Sources: FAOSTAT, China Statistical Yearbook.

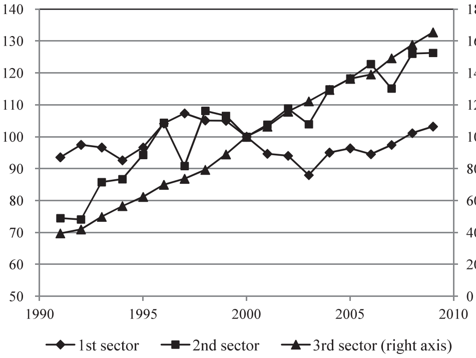


Figure 1. Producer price indexes by sector

Note: The author's computation are based on FAOSTAT.

(China's central government has been barring the use of maize as feedstock for biofuel since grain prices soared in 2007–2008.) As a result of rapid changes in Chinese diets associated with economic growth, demand for these products is expected to grow in the future. Since the CSY does not record production volume for the third sector, we use FAOSTAT instead.[3] Production of vegetables and fruits increased nearly tenfold, from 65 million tons to 639 million tons, between 1980 and 2009, and the sector has maintained complete self-sufficiency.

Areas sown with the first-sector crops accounted for more than half of the total area until the mid-1990s, but the sector's share declined sharply to 41.5% in 2009. It should be noted, however, that the sector remains the most dominant in terms of land-use at present, maize occupies the largest sown area of any single crop. In contrast, the shares of sown areas for the second and third sectors show an upward trend during 1980–2009. Considering production value, the first sector's share plummeted from 50.9% in 1991 to 25.9% in 2009, while that of the second sector was level until the mid-2000s, then declined. Most noteworthy in Table 1 is that the share of production value for vegetables and fruits nearly doubled from 30.0% in 1991 to 58.9 % in 2009. The fact that the share of production value is higher than that of sown area for the third sector arises from the fact that this sector's land productivity is among the highest. This is not specific to Chinese agriculture but rather a general trait of labor-intensive horticulture.

2) Prices of agricultural products

To consider prices, the Laspeyres index is computed for producers' price in each sector, using FAOSTAT; the results are illustrated in Figure 1. Although the Statistics on Farm Product Costs and Revenues (SFPCR), published by the China Statistical Bureau, is an available alternative data source, we use FAOSTAT because it covers a wider range of items.[4] According to Huang *et al.* (2009), Ikegami (1994), and Martin (2001), the year 1991 was a turning point for China's agricultural price policy: the government, acting in the interest of farmers, introduced the price-support program, putting an end to the scissors-form differential price system (or below-market procurement pricing system) that had been in place. As shown in Figure 1, the price of grain, particularly feed grain, rose sharply during 1991–1996. However, the reform was accompanied by a rapid rise in producer's prices and overstocked inventory and created a huge financial burden. The government thus reversed the pricing policy, shifting toward liberalization, before China acceded to the WTO in 2001 (Ito and Ni, 2013). As a result, prices in the first and second sectors stagnated from the late 1990s to the early 2000s. The price index of the third sector, on the other hand, moved linearly upwards from 1991 to 2009. This is partly because demand for vegetables and fruits grew substantially during this period and partly because prices per unit weight of these products increased gradually. The rise in unit prices was caused by farmers switching their production from traditional high-weight crops to high-value-added ones.

Although price-support programs are still in place for some crops in the first and second sectors, there is no significant difference between farm-gate and border prices (Huang *et al.*, 2009). It should be noted, however, that during 2010–2012, after the period studied here, prices received by farmers increased by a large margin and were, on average, 13% higher than

3) Data on production volume of the first and second sectors is available from the CSY and FAOSTAT. The margin of error between statistics from the two sources is less than 1%.

4) The FAOSTAT reports that the price of maize soared in 2000 to be nearly three times as expensive as it had been in the previous year. This is inconsistent with the statistical figures reported in the CSY and SFPCR. Assuming that the FAOSTAT statistics are erroneous, we correct the price data using the SFPCR.

those observed in the world market (OECD, 2013). Currently, the price of oilseed is significantly influenced by the international market, partly because China's comparative advantage in oilseeds has been lost and partly because the out-of-quota tariff rate was reduced substantially in the early 2000s (Cheng, 2008; Yang *et al.*, 2008). Among the major crops grown in China, only rice maintains its international competitiveness, though Huang *et al.* (2009) reports that rice producers used to be among the most heavily taxed farmers in China. The domestic free on board (FOB) price of wheat has been 1.0–1.5 times the international price for the past two decades. Maize, one of China's most dominant and important crops, is barely sustaining its international competitiveness at the CIF (cost, insurance, and freight) price (Ikegami, 2007). Although the disparity between domestic and foreign prices is larger for maize than for soybeans, maize exports outstrip imports in some years because the government and/or parastatal trading enterprises retain a decisive influence on markets due to large inventories and value-added tax rebates or *de facto* export subsidies (Hoken, 2010; Huang *et al.*, 2009; Kawahara, 2010; Yang *et al.*, 2008).

3) Land use policy and the PSP

When land-use characteristics of agriculture are taken into consideration, sown areas are likely to directly affect farm production quantity, all else equal. China' Comprehensive Plan for National Land Use, released in 2006, stipulates that the cultivated areas in 2010 and 2020 shall not be less than 1.818 billion Mu and 1.805 billion Mu, respectively (1 Mu = 1/15 hectare). It also emphasizes the need to retain no less than 1.56 billion Mu of basic farmlands for grain production. In addition to this emphasis, the document refers to the necessity of ensuring the quality of these lands (Chen, 2007). The Basic Farmland Protection Regulation of 1994 and its successive amendment set strict limits on the encroachment of development zones into farmland under the comprehensive land use plan. In order to ensure that county and township governments observe these guidelines, thereby restraining urbanization-driven development of farmland, the upper government is obliged to oversee these operations.

In 1986, the government enacted the Land Management Law (LML), which continues to legally dominate all regulations and directives

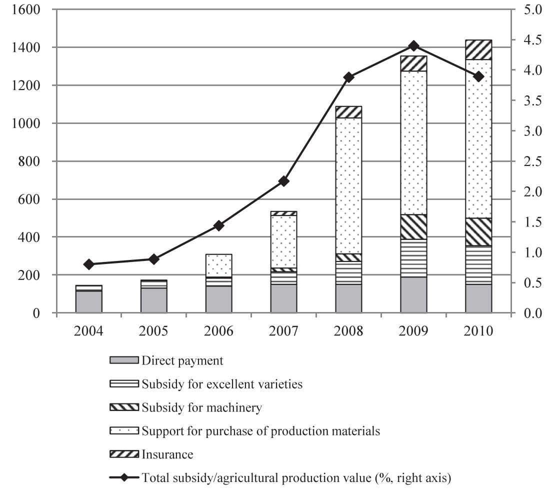


Figure 2. The PSP subsidies (100 million yuan)

Source: Ministry of Agriculture, Forestry, and Fisheries (2011).

regarding land use policy in China. The 1999 revised version of the LML "requires provincial governments to adopt measures to ensure that the total amount of cultivated land within its administration region is not reduced, and if reduced to take responsibility for the reclamation of an equal amount of land within its administration region or in a different location" (Ho and Lin, 2003: p. 695). It is believed that this strategy is the most crucial factor for enabling China to stabilize food supply and sustain food security (Chen, 2011; Lichtenberg and Ding, 2008; Yang and Li, 2000). In spite of these strict regulations, the loss of cultivated land for grain production has accelerated significantly since the mid-1990s. In particular, it decreased by 13.8 million hectares, or 12.2%, between 1999 and 2003. However, soon after the PSP was implemented in 2004 this trend reversed dramatically, with the areas increasing by 9.6 million hectares from 2004 to 2009. As a result, quantity of grain produced reached a record high of 546 million tons in 2010.

The PSP was designed to promote grain production while simultaneously enhancing farm income through direct payments to farmers based on their cultivated areas. In some regions, the subsidies are paid to farmers based on total sown areas, instead of those sown with grain crops. The program is composed of five operations: (a) direct payments to grain growers; (b) subsidies for adoption of certain improved varieties; (c) subsidies for farm machinery purchases; (d) comprehensive support for purchasing production materials; and (e) agricultural insurance.

Figure 2 illustrates the total amount of PSP subsidies provided during 2004–2010 (Ministry of Agriculture, Forestry and Fisheries, 2011). It increased from 14.5 billion Yuan in 2004 to 143.8 billion Yuan in 2010, reaching 4.4% of the total agricultural production value in 2009 (it declined slightly to 3.9% in 2010). The production materials subsidy payment (d) accounted for more than half of the total amount in 2010, although (a) was the largest component when the PSP first went into effect. Meanwhile, budgetary expenditures on the PSP accounted for over 20% of agricultural appropriations at the central government level in 2010 (Kusano and Koyama, 2010). China has a regional comparative advantage in cash crop production, not grain production, due to its factor endowments of a scarcity of arable land relative to farm labor. As such, it appears that the program helped convert more rural resources to grain production than would otherwise be possible.

In addition to the PSP, the government introduced the Grain Purchasing Policy at Minimum Prices (GPP) for wheat and rice in 2004, and the Temporary Stockpiling Policy (TSP) for maize and soybeans in 2007 and 2008, respectively. The government is supposed to implement these programs only when market prices fall below the established minimum prices and apply them only in the leading production regions (Carter *et al*., 2012). However, there is no doubt that the recovery of grain production after 2003 is a reflection of farmers' enhanced motivations to produce more grain, driven by a wide array of subsidy payments and price-support schemes.[5] The consistency of these interventional policies in grain markets with the international treaty of the WTO Agreement on Agriculture (AoA) must be questioned because the PSP, GPP, and TSP are all considered to be "amber box" supports.[6] Since China has no Aggregate Measurement of Support commitment, subsidy payments for trade-distorting domestic support to farmers cannot exceed the given *de minimis* limit, or 8.5% of the agricultural production value (Cheng *et al*., 2008). The ratio of PSP subsidies to total agricultural production value does not reach this limit, as shown in Figure 2. However, it is widely believed that budgetary expenditures for price-support programs in agriculture, such as GPP and TSP, are of like size or more than subsidy outlays for the PSP (Hoken, 2003). Thus, it is likely that China's domestic support has come close to the limit agreed in the AoA, which arguably restricts the government's discretionary power to extend its *de minimis* subsidy measures.

We will return to these policy issues in the conclusion, but the next section builds on this background to describe the analytical approach used to examine the impact of the PSP in this paper.

3. ODF and Technical and Allocative Efficiencies

This section provides a brief overview of the stochastic frontier ODF and explains how to measure technical and allocative efficiency scores based on Coelli and Perelman (2000), Lovell *et al.* (1994), and O'Donnell and Coelli (2005). We assume, to begin with, the following production possibility set:

$$P(\boldsymbol{X}) = \{\boldsymbol{Y} \in R_{+}^{M} : \boldsymbol{X} \text{ can produce } \boldsymbol{Y}\},$$

where the vectors $\boldsymbol{X}$ and $\boldsymbol{Y}$ denote inputs and outputs. The ODF is defined as

$$D_O(\boldsymbol{X}, \boldsymbol{Y}) = \min\{\theta : (\boldsymbol{Y}/\theta) \in P(\boldsymbol{X})\},$$

where θ is defined as a distance parameter that is less than or equal to 1. The ODF is non-de-

5) Grain production in Henan, Heilongjiang, Shandong, Jiangsu, Sichuan, Anhui, and Hebei accounted for around half of the total volume. Sown areas for grain production in these seven provinces increased by 12.8% during 2003–2009.

6) Huang *et al.* (2011) claim that the PSP is categorized into "green box" policies in the WTO agreements because it has no incremental effect on grain production. Their argument is based on the conjecture that PSP subsidies are paid to land contractors who are not necessarily land tillers, and therefore the policy has no distortional effect of altering farmer's planting decisions. This is consistent with the argument of Feng *et al.* (2009). This, however, would lead to debates about why aggregate grain production bounced back after 2003. Furthermore, to the extent that the subsidy payment amounts are linked directly to acreage used for the current year's production, PSP is in principle categorized as an "amber box"policy (Cheng, 2008).

creasing, linearly homogeneous and convex in $\boldsymbol{Y}$, and non-increasing and quasi-convex in $\boldsymbol{X}$. From homogeneity of degree one in $\boldsymbol{Y}$, we have $\ln\lambda D_O(\boldsymbol{X}, \boldsymbol{Y}) = \ln D_O(\boldsymbol{X}, \lambda\boldsymbol{Y})$. Thus, the following equation is obtained by assuming $\lambda = 1/Y_1$:

$$\ln Y_1 = -\ln D_O(\boldsymbol{X}, \boldsymbol{Y}/Y_1) + \ln D_O(\boldsymbol{X}, \boldsymbol{Y}). \quad (1)$$

Since we have $0 < D_O(\boldsymbol{X}, \boldsymbol{Y}) \leq 1$, $u = \ln D_O(\boldsymbol{X}, \boldsymbol{Y})$ is negative with the maximum value equal to zero. (We have $D_O(\boldsymbol{X}, \boldsymbol{Y}) = 1$ on the production frontier surface.) This term u represents the inefficiency element with a one-sided disturbance; the closer the value is to 1, the more technically efficient farmers' choices are. Substituting $u = \ln D_O(\boldsymbol{X}, \boldsymbol{Y})$ into equation (1), we have

$$\ln Y_1 = -\ln D_O(\boldsymbol{X}, \boldsymbol{Y}/Y_1) + u. \quad (2)$$

In this study, the farm sector is categorized into three groups. Thus, by letting Y_j^* be Y_j/Y_1 (j=2, 3) and specifying $-\ln D_O(\boldsymbol{X}, \boldsymbol{Y}/Y_1)$ in equation (2) in the trans-log (TL) form, we express the stochastic frontier production function as

$$\begin{aligned}\ln Y_{1i} = {} & \alpha_0 + \sum_k \alpha_k \ln X_{ki} + \sum_l \alpha_{lt} t \ln X_{li} + \sum_m \beta_m \ln Y_{mi}^* \\ & + \sum_n \beta_{nt} t \ln Y_{ni}^* + \frac{1}{2}\sum_k\sum_l \alpha_{kl} \ln X_{ki} \ln X_{li} \\ & + \frac{1}{2}\sum_m\sum_n \beta_{mn} \ln Y_{mi}^* \ln Y_{ni}^* \\ & + \sum_k\sum_m \gamma_{km} \ln X_{ki} \ln Y_{mi}^* + \gamma_t t + \gamma_{tt} t^2 + u_i + v_i, \end{aligned} \quad (3)$$

where t and i demote the time-trend variable and province, respectively. v_i represents the stochastic term independently $N(0, \sigma_v^2)$ distributed over the observations. The terms u_i are technical efficiency scores and are assumed to be independently $N^+(\mu, \sigma_u^2)$ distributed with the truncation point at zero, as described above. Parameters in equation (3) have the restrictions $\alpha_{kl} = \alpha_{lk}$, $\beta_{mn} = \beta_{nm}$ from symmetric conditions.

By applying the Shephard's lemma to the ODF, the shadow price of output (sector) k is given by

$$\frac{\partial D_O(\boldsymbol{X}, \boldsymbol{Y})}{\partial Y_k} = r_k(\boldsymbol{X}, \boldsymbol{Y}).$$

Thus, the condition for farm-revenue maximization for a given technology and specific amounts of inputs can be expressed as

$$\frac{r_m}{r_n} = \frac{p_m}{p_n}, \quad (4)$$

where p_k with $k = m, n$ denotes the actual output price for k.[7] In the case that $r_m/r_n > p_m/p_n$, we understand that sector m is producing excessively relative to sector n (and vice versa). From equations (1) and (3), we have

$$\frac{\partial \ln D_O}{\partial \ln Y_j} = -\frac{\partial \ln Y_1}{\partial \ln Y_j^*} \equiv \beta_j^{TL} \quad (j = 2, 3).$$

Since the ODF is homogenous of degree one, we have[8]

$$\frac{\partial \ln D_O}{\partial \ln Y_1} \equiv \beta_1^{TL} = 1 - \sum_{j \neq 1} \beta_j^{TL}.$$

As the ODF is non-decreasing in $\boldsymbol{Y}$, $\beta_i^{TL} \geq 0$ (i = 1, 2, 3) are to be met. Finally, the allocative efficiency score can be expressed as

$$\mathrm{AE}_{mn}(1) = \frac{\beta_m^{TL}/\beta_n^{TL}}{p_m Y_m / p_n Y_n}. \quad (5)$$

When $\mathrm{AE}_{mn}(1)$ is larger (smaller) than 1, products in sector m are over (under)-produced relative to those in sector n. In other words, in the case that $\mathrm{AE}_{mn}(1)$ is not equal to 1, the product mix between the m and n sectors is allocatively inefficient. In equation (5), the production value of sector k is given by $p_k Y_k = \Sigma_{i=1}^{l} p_k^i Y_k^i$, where p_k^i and Y_k^i represent nominal price and production volume of item i in the sector k, respectively. Alternatively, the allocative efficiency score can be computed based on the following equation:

$$\mathrm{AE}_{mn}(2) = \frac{r_m/r_n}{p_m/p_n}, \quad (6)$$

where p_k with $k = m, n$ denotes the unit price in sector k, defined as the production value divided by the production volume.

4. Data

This study draws on province-level data from 1991 to 2009 to estimate the ODF. The major data sources are the CSY and FAOSTAT. Although Chongqing was separated from Sichuan Province in 1997 as a municipal administrative area, they are integrated in this analysis. As a result, data from 30 provinces is available for

7) Equation (4) is obtained by solving the following optimization problem

$$\begin{aligned} \max \quad & p_m Y_m + p_n Y_n \\ \text{s.t.} \quad & D_O(Y_m, Y_n, \boldsymbol{X}) = \theta. \end{aligned}$$

8) Since the ODF is homogeneous of degree one, we have $D_O(\lambda\boldsymbol{Y}) = \lambda D_O(\boldsymbol{Y})$. Taking the log of this equation and differentiating the result with respect to λ, we have $\sum \partial \ln D_O / \partial \ln Y_j = 1$ when λ=1.

each year. Output is measured as weight (in 10,000 tons) for each sector. Since the CSY does not provide output data for the third sector for each province, we estimate it by prorating the full amount of fruit and vegetable production, obtained from FAOSTAT, based on the sown area ratio for each province.[9] Data on horticultural production is available for some provinces from the Provincial Statistical Yearbooks (PSY). However, most provinces did not release such data in the 1990s, some do not do so even today. In Appendix Figure 1, we compare the production volumes estimated in this study with those obtained from the PSY in 2001. Gale (2002) points out that the provincial statistics tend to overestimate production not only for agriculture, which is consistent with Appendix Figure 1.

Factor inputs are fertilizer, farm labor, farm machinery, and sown area. Fertilizer is measured by the weight of its net ingredients (10,000 tons). Other inputs, such as pesticides, farm manure, and seeds should ideally be included as intermediate inputs, but data on these factors is not available. Labor input is measured as the total number of workers engaged in production (10,000 people). Capital input is measured by farm machinery power used for production (10,000 kW). The CSY provides data on factor inputs used for agricultural production as a whole, with the exception of the sown area. We estimate factor inputs used for production of the three sectors by prorating the whole amount by the sown area ratio, a method that aligns with Yao *et al.* (2001). Other explanatory variables used in the ODF include a time trend variable (*Time*) as a proxy for technological progress, the irrigation rate (*Irrigation*), and the natural calamity index (*Damage*).

5. ODF Estimation Results and Discussion

The middle two columns of Table 2 present the estimation results when the ODF is specified in the Cobb-Douglas (CD) form, while the rightmost columns present the results when the ODF is specified in the TL form.[10] In order to remove possible estimation bias stemming from unobserved, time-invariant covariates, we include fixed effects in the estimation. The negative coefficients on ln(sec. 2) and ln(sec. 3) suggest that grain production for staple foods is a substitute for grain production for processing and feeds and for fruit and vegetable production. In addition, many cross-term coefficients are significantly different from zero, suggesting that the ODF should be specified in a flexible functional form i.e., TL rather than CD. Gamma, representing $\sigma_u^2/(\sigma_v^2+\sigma_u^2)=\sigma_u^2/\sigma^2$, is 0.458 for the CD and 0.904 for the TL and statistically different from zero (the standard error of gamma is 0.085 for the CD and 0.036 for the TL). The estimated ODF function satisfies the regulatory condition of convexity in $\boldsymbol{Y}$ for most data domains, but it does not satisfy the quasi-convex condition in $\boldsymbol{X}$ (linear homogeneity in $\boldsymbol{Y}$ is imposed *a priori*).[11]

1) Estimation results for technical and allocative efficiencies

Table 3 shows the results of estimating the average technical and allocative efficiency scores of each province during 1991–2009. One can see at a glance that the technical efficiency scores vary widely across provinces, ranging from 0.536 for Tibet (the least efficient) to 0.978 for Beijing (the most efficient). Although the allocative efficiency scores of AE_{12} are distributed around unity, those of AE_{13} and AE_{23} are far above unity for almost all provinces, indicating that grains are produced excessively relative to vegetables and fruits. Chen *et al.* (2008) estimated technical efficiencies of Chinese agriculture during 1990–2003, using a non-parametric data envelopment analysis (DEA). Although the estimation period is somewhat different from this study, the correlation coefficient of the efficiency scores between the two studies is 0.63.

9) Data on fruit production volumes is obtained from the CSY for each province after 2003. The correlation coefficient between the data and the figures estimated in this paper is around 0.7.

10) When $Time^2$ is included in equation (3) as an additional covariate, the monotonicity condition for farm machinery, $\partial D_0/\partial X_k<0$, is violated for some data domains. Thus, it was excluded from the ODF estimation. The rate of technological progress computed from the ODF estimators in this study is 1.3% for the period average, which is consistent with Jin *et al.* (2010) who estimated a stochastic frontier production function for China's grain sector from 1985 to 2004.

11) O'Donnell and Coelli (2008) estimated the ODF using data on the European railroad industry. In their estimation, the quasi-convex condition in $\boldsymbol{X}$ is violated for some data domains.

Table 2. Estimation results of the ODF

	CD form		TL form	
	Estimates	z-values	Estimates	z-values
ln (*fer*)	0.069**	2.36	0.303***	6.47
ln (*lab*)	0.186***	6.22	0.075*	1.72
ln (*cap*)	0.072***	3.22	0.064**	2.05
ln (*lad*)	0.734***	20.54	0.484***	5.98
ln (*sec. 2*)	−0.307***	−25.87	−0.290***	−13.71
ln (*sec. 3*)	−0.253***	−19.31	−0.313***	−14.24
Time	−0.016***	−2.65	0.011***	3.90
ln (*fer*)*ln (*lab*)			−0.013	−0.17
ln (*fer*)*ln (*cap*)			−0.166***	−2.69
ln (*fer*)*ln (*lad*)			0.040	0.30
ln (*fer*)**Time*			−0.008**	−2.00
ln (*lab*)*ln (*cap*)			−0.148***	−2.59
ln (*lab*)*ln (*lad*)			−0.199*	−1.79
ln (*lab*)**Time*			0.016***	3.38
ln (*cap*)*ln (*lad*)			0.183**	2.00
ln (*cap*)**Time*			−0.009***	−3.38
ln (*lad*)**Time*			−0.005	−0.76
ln (*fer*)*ln (*fer*)			0.204*	1.90
ln (*lab*)*ln (*lab*)			0.270***	2.74
ln (*cap*)*ln (*cap*)			0.148***	3.18
ln (*lad*)*ln (*lad*)			−0.104	−0.51
ln (*sec. 2*)*ln (*fer*)			0.101***	3.34
ln (*sec. 2*)*ln (*lab*)			0.059*	1.88
ln (*sec. 2*)*ln (*cap*)			0.028	1.31
ln (*sec. 2*)*ln (*lad*)			−0.210***	−4.44
ln (*sec. 2*)**Time*			−0.006***	−3.65
ln (*sec. 3*)*ln (*fer*)			−0.091**	−2.09
ln (*sec. 3*)*ln (*lab*)			−0.055	−1.35
ln (*sec. 3*)*ln (*cap*)			0.047	1.61
ln (*sec. 3*)*ln (*lad*)			0.115**	2.23
Ln (*sec. 3*)**Time*			0.005**	2.18
ln (*sec. 2*)*ln (*sec. 3*)			0.014	0.82
ln (*sec. 2*)*ln (*sec. 2*)			−0.112***	−5.69
ln (*sec. 3*)*ln (*sec. 3*)			−0.107***	−5.18
Irrigation	−0.023	−0.32	−0.196**	−2.54
Damage	−0.059**	−2.03	−0.044**	−2.10
Const.	0.278**	2.26	0.257***	2.80
Sigma^2	0.015		0.036	
Gamma	0.458		0.904	
Log likelihood	505.91		727.51	
Number of observations	569		569	

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. *fer*: fertilizer, *lab*: labor, *cap*: farm machinery, *lad*: sown areas, *sec. 2*: Y_2^*, *sec. 3*: Y_3^*. The third sector for Tibet in 1995 is dropped from the observations.

Table 3. Period average of technical and allocative efficiency scores

	Technical eff.		AE_{12}		AE_{13}		AE_{23}	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Beijing	0.978	0.002	1.82	0.29	3.89	1.48	2.18	0.81
Tianjin	0.754	0.015	1.56	0.22	4.00	0.97	2.56	0.48
Hebei	0.680	0.019	1.21	0.15	3.20	1.29	2.68	1.12
Shanxi	0.572	0.023	1.08	0.14	2.50	0.77	2.31	0.54
Inner Mongolia	0.743	0.016	0.99	0.13	2.58	0.60	2.63	0.66
Liaoning	0.829	0.011	1.35	0.11	2.14	0.59	1.60	0.48
Jilin	0.811	0.012	1.54	0.13	1.30	0.43	0.84	0.28
Heilongjiang	0.809	0.012	0.88	0.08	2.72	1.77	3.15	2.04
Shanghai	0.939	0.004	1.40	0.82	3.33	1.53	3.68	3.27
Jiangsu	0.671	0.019	0.80	0.17	2.10	0.93	2.94	1.95
Zhejiang	0.749	0.015	2.22	1.74	3.32	1.83	2.57	1.68
Anhui	0.593	0.022	0.71	0.13	1.80	0.79	2.62	1.32
Fujian	0.976	0.002						
Jiangxi	0.587	0.022	0.41	0.05	2.46	1.09	5.94	2.28
Shandong	0.850	0.010	1.18	0.14	2.57	1.09	2.18	0.92
Henan	0.706	0.017	0.93	0.14	2.06	0.82	2.22	0.86
Hubei	0.647	0.020	0.60	0.06	2.01	0.84	3.39	1.46
Hunan	0.680	0.019	0.58	0.08	2.26	1.02	4.07	2.14
Guangdong	0.883	0.008	9.02	11.67	3.14	1.16	0.85	0.63
Guangxi	0.602	0.022	0.57	0.06	2.91	1.18	5.15	2.04
Hainan	0.798	0.013	1.85	1.02	3.02	1.26	1.40	0.97
Chongqing-Sichuan	0.914	0.006	0.52	0.06	1.69	0.74	3.33	1.61
Guizhou	0.660	0.019	0.54	0.06	1.70	0.81	3.16	1.60
Yunnan	0.571	0.023	0.73	0.11	1.75	0.64	2.48	1.11
Tibet	0.536	0.024	1.73	1.47	2.00	0.94	1.53	0.86
Shaanxi	0.608	0.021	0.89	0.12	2.28	0.93	2.55	0.98
Gansu	0.626	0.021	0.63	0.09	2.34	0.85	3.86	1.69
Qinghai	0.546	0.023	0.81	0.12	2.05	0.74	2.61	1.14
Ningxia	0.582	0.022	0.95	0.16	2.00	0.76	2.19	1.03
Xinjiang	0.584	0.022	0.70	0.14	1.94	0.73	3.04	1.80

Note: Allocative efficiencies for Fujian are not reported because monotonicity of outputs is violated.

On the other hand, Carter and Estrin (2001), using a stochastic frontier ODF model, estimated allocative efficiencies of Chinese agriculture during 1986-1995. Their estimation is more restrictive in terms of production technology than the present study in that the ODF is specified in the CD form. However, a correlation coefficient of the allocative efficiencies, AE_{23}, between the two studies is 0.71. Thus, the efficiency scores found in this study do not seem to have serious contradiction with those estimated by previous studies.[12)]

2) Determinants of technical efficiencies

The regression analysis, aiming to identify factors that influence technical efficiencies, uses the following variables as regressors: the share of sown areas in the national total (*SOWN*): the ratio of sown areas to farm labor (*SLR*): the ratio of sown areas to farm machinery (*SMR*): the specialization coefficients of production for each sector (*SPE 1-3*); the larger the coefficient, the more advanced the production specification is for the sector. The appendix explains how the specialization coefficients are computed. The above six variables are measured at the

Table 4. Panel analyses of technical efficiencies

	Random effect		Standard Tobit	
	Estimates	*z*-values	Estimates	*z*-values
Share of sown areas (*SOWN*)	0.341***	3.28	1.654***	14.49
Ratio of sown areas to farm labor (*SLR*)	0.011***	3.04	0.025***	4.46
Ratio of sown areas to farm machinery (*SMR*)	0.004***	6.84	0.003***	5.01
Specialization coeff. of the first sector (*SPE 1*)	0.036***	10.54	0.103***	28.33
Specialization coeff. of the second sector (*SPE 2*)	0.018***	6.49	0.046***	17.93
Specialization coeff. of the third sector (*SPE 3*)	0.011***	7.68	0.044***	41.11
Time (*Time*)	0.002***	20.28	0.003***	13.52
Price Support Program dummy (*PSPA*)	−0.001	−0.67	0.000	0.20
Producer Subsidy Program dummy (*PSPB*)	−0.002**	−2.42	−0.003**	−2.14
Constant	0.627***	34.06	0.345***	93.92
overall R^2	0.176		—	
Likelihood	—		1750.7	
Numbers of observations	569		569	

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

provincial level. Additional regressors are the time trend (*Time*): a Price Support Program dummy (*PSPA*), equal to 1 during the period when the program was in place (1991–1999) and 0 otherwise: a Producer Subsidy Program dummy (*PSPB*), equal to 1 during the period when the program was in place (2004–2009) and 0 otherwise. There are many other time-variant covariates that could influence the efficiency scores, such as farmland fragmentation, farmers' educational level, labor market characteristics, local government regulations, and provision of public goods and services. However, these are not available due to data restrictions.

The first column of Table 4 shows the results of estimating a random effects model, used to control for the time-invariant, unobservable characteristics of individual provinces. We selected the random effects model since the fixed effects model was rejected as a result of the Hausman specification test. Given that the dependent variables (technical efficiency scores) are censored at 1, we alternatively employ the random-effects Tobit model and show the estimation results (the average marginal effects) in the second column.[13] There are no contradictions with respect to coefficient signs between the two estimators. The coefficient on *PSPA* is not statistically significant, while the rest of the coefficients are significantly different from zero (significant at the 5% level for *PSPB* and at the 1% level for all others). *SOWN* is positively associated with technical efficiency, suggesting that a 1% increase in the share of sown areas in the national total is expected to increase the technical efficiency score by 1.654%. Positive coefficients on *SLR* and *SMR* indicate that provinces with large operational size and adequate capital equipment have the advantage in maintaining high technical efficiencies.[14] *SPE 1–3* are highly significant and of the expected sign, suggesting that farm production is technically efficient in provinces with high degrees of specialization. The variable *Time* has a positive and

12) There is no significant correlation of allocative efficiencies between the AE_{13} estimated in this study and that estimated by Carter and Estrin (2001).

13) Chavas *et al.* (2005), Coelli *et al.* (2002), and others use the Tobit model by taking account of the fact that the efficiencies are the upper limits of the scores.

14) We include SLR^2 and SMR^2 as additional covariates in order to capture a curvilinear effect of *SLR* and *SMR* on technical efficiencies. However, we found no results of particular interest. In this study, *SMR* is positively associated with technical efficiencies, a result that is inconsistent with Monchuk *et al.* (2010) but consistent with Chen *et al.* (2009). Tian and Wan (2000) find mixed results regarding the relationship between *SLR* and technical efficiency scores, with a positive association for rice but a negative association for wheat.

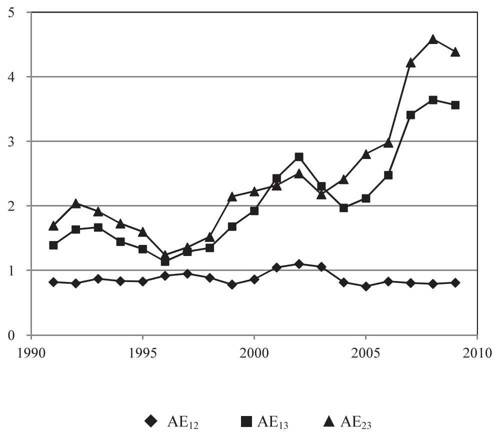


Figure 3. Changes in allocative efficiencies (I)

significant coefficient, which indicates that technical efficiencies improve as time passes i.e., farmers have learned farming practices over the years, leading to positive learning-by-doing effects on farm management (Foster and Rosenzweig, 1995).[15] Most noteworthy in this analysis is that the *PSPB* has a negative coefficient. This strongly suggests that PSP has a distorting effect on farmers' ability to make efficient technical choices.

3) Trends in allocative efficiencies

Using equation (5), we compute the national average of allocative efficiency scores for 1991–2009 and show the results in Figure 3. Appendix Figure 2 illustrates the results when equation (6) is used for the computation; there are no serious contradictions between the two estimators, so we base our discussion on Figure 3. We see from the figure that AE_{12} remains almost level, below 1 for the entire period except 2001–2003 (the period average of AE_{12} is 0.87). This suggests that the second sector is slightly over-produced relative to the first sector. As noted in Section 2, although demand for the second sector products has been growing over the past decade, it is on the verge of losing its international competitiveness. Despite this, the Chinese government has tried to boost production of grain for processing and feed, particularly maize. Thus, if this policy orientation continues in the future, the allocative efficiency between the first and second sectors is highly likely to worsen further under downward pressure on prices in the second sector.[16]

Figure 3 illustrates that the allocative efficiency scores for AE_{13} and AE_{23} began to decline gradually in the early 1990s and approached 1 in 1996. The scissors-form differential price system for grains ended in the early 1990s, as described in Section 2. Thus, the prices in the early 1990s should reflect the supply-demand balance of the grain market. If this is the case, we can say that farmers' product mix choices in the mid-1990s were efficient and rational. However, the scores for AE_{13} and AE_{23} began to rise thereafter, declining again during the time when grain production stagnated. Most noteworthy in Figure 3 is that the efficiency scores have risen gradually since the mid-2000s to be far above unity in the late 2000s; this suggests a substantial degree of overproduction of the first and second sectors relative to the third. This naturally raises the question of what driving force was behind the diversion of crop portfolios away from the income-maximizing combination.[17]

4) Determinants of allocative efficiencies

To consider determinants of allocative efficiencies, we use a regression analysis, with $AE_{mn}(2)$ as the dependent variable; results are shown in Table 5. Due to the small variance, it

15) Technical efficiencies computed in this study improve for all provinces as time passes, contradicting the results of Zhang and Brümmer (2011). They attribute a negative relationship between *Time* and technical efficiencies to the under-development of factor markets, institutional impediments to migration (the *hukou* system), and incomplete land reform. However, there is no evidence that the reform of these institutions slowed over the past decades in rural China.

16) Allocative efficiencies do not necessarily worsen if the government uses price incentives to boost grain production and farmers respond to these. In this case, allocative efficiencies are not eligible for the measurement of resource allocation efficiencies.

17) Many scholars insist that Chinese agriculture should pursue diversification and selective expansion of farm products from the viewpoint of comparative advantage and that this is consistent with efficient resource allocation and farm income maximization (Martin, 2001; Wen, 2006; Yang, 2006). It should be noted, however, that per capita vegetable consumption, particularly of leafy vegetables that occupy large sown areas, reached a saturation point in Chinese diets (Kawahara and Yoshida, 2007).

Table 5. Panel analyses of technical efficiencies (standard Tobit)

	AE_{13}		AE_{23}	
	Estimates	z-values	Estimates	z-values
Share of sown areas (*SOWN*)	2.500	0.62	7.265	0.63
Ratio of sown areas to farm labor (*SLR*)	−0.088	−0.28	2.709***	5.02
Ratio of sown areas to farm machinery (*SMR*)	0.261***	4.98	−0.164**	−2.01
Specialization coeff. of the first sector (*SPE 1*)	−0.179	−0.68	—	
Specialization coeff. of the second sector (*SPE 2*)	—		−1.889***	−4.85
Specialization coeff. of the third sector (*SPE 3*)	1.057***	6.82	1.524***	6.61
Agriculture dependency ratio (*ADR*)	−0.838*	−1.73	−3.963***	−5.16
Price Support Program dummy (*PSPA*)	−0.759***	−8.08	−0.215	−1.54
Producer Subsidy Program dummy (*PSPB*)	0.281***	3.23	1.244***	9.49
Constant	1.702***	3.11	3.714***	4.08
Likelihood	−511.0		−740.2	
Numbers of observations	519		519	

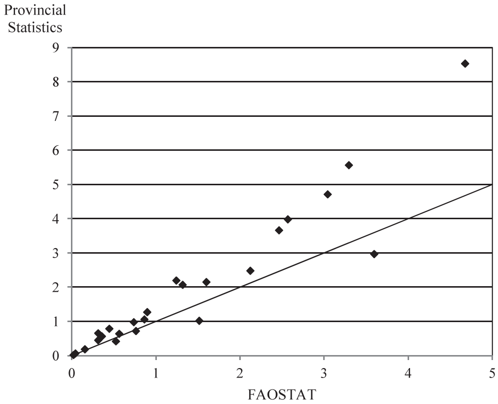
Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Some observations do not satisfy the regulatory conditions of the ODF. As a result, nine percent of the obs are excluded from the analyses.

was not possible to perform a similar analysis of $AE_{12}(2)$. The regressors used in this analysis are very similar to those in Table 4. Instead of *Time*, we use a variable for the agriculture dependency ratio (*ADR*), which is defined as incomes from farming divided by total household incomes; the larger the value, the more heavily farm households depend on farm-related income for their livelihoods.[18] The national average of *ADR* declined sharply from 0.83 in 1991 to 0.49 in 2009, with large inter-provincial variance. It is reasonable to hypothesize that farm households that depend more heavily on farm income have a strong incentive to make their farm product mix more efficient and profitable.

The number of observations with $AE_{13}(2)$ or $AE_{23}(2)$ less than 1 are only 15 and 39, respectively, out of 519. Thus, we consider an increase in a continuous variable with a negative estimated regression coefficient to result in greater allocative efficiency, whereas an increase in a continuous variable with a positive coefficient results in greater allocative inefficiency. None of our conclusions change vastly when observations with $AE_{mn}(2)$ less than 1 are excluded from the regression analysis. As shown in Table 5, *SOWN* is positively associated with $AE_{13}(2)$ and $AE_{23}(2)$, suggesting that grains are over-produced in provinces that occupy a larger share of the country's sown area. However, the coefficients are not significant. The *SLR* variable is negatively associated with $AE_{13}(2)$ and positively associated with $AE_{23}(2)$. In contrast, the *SMR* variable is positively associated with $AE_{13}(2)$ and negatively associated with $AE_{23}(2)$. There is a possibility that *SLR* and *SMR* are proxies for some unobservable time-variant variables, complicating interpretation of the results.

SPE 1 and *SPE 2* are negatively associated with $AE_{13}(2)$ and $AE_{23}(2)$, respectively. This suggests that the over-production of grains is to some extent alleviated in provinces whose major crop is grain, which seems logical. In contrast, *SPE 3* is positively associated with $AE_{13}(2)$ and $AE_{23}(2)$, suggesting that grains are over-produced in provinces that have an advantage in horticulture. In other words, farmers in these provinces could have increased their farm income had they devoted more resources to fruit and vegetable production. The coefficients on *ADR* are negative and significant for both $AE_{13}(2)$ and $AE_{23}(2)$. These results lend strong support to our hypothesis that farm households that are highly dependent on farm income for their livelihoods are strongly motivated to

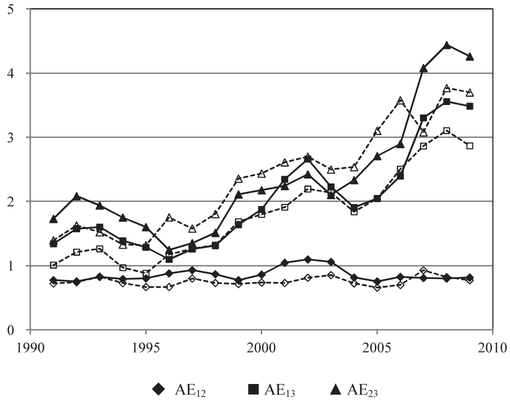
18) The reason for *Time* being dropped as a covariate is multicollinearity with *ADR*.



Appendix Figure 1. Estimates of the third sector production (10 MT)

Source: Statistical Yearbook of Province.

Note: Fujian, Jiangxi, Guangxi, Chongqing, Sichuan, Guizhou, and Yunnan are excluded.



Appendix Figure 2. Changes in allocative efficiencies (II)

Note: Dashed lines represent the results when price data of SFPCR are used.

choose more efficient and profitable product mixes. The coefficient on *PSPA* is negative for $AE_{13}(2)$ and $AE_{23}(2)$, indicating that allocative efficiencies improved when the Price Support Program was in place between 1991 and 1999. The most noteworthy finding from this analysis is the positive coefficient on *PSPB*, which clearly demonstrates that the Producer Subsidy Program distorts market signals, while leading farmers to choose inefficient product mixes.

6. Conclusion

This study has examined farmers' crop-choice rationality in Chinese agriculture via estimation of a stochastic frontier ODF, which accommodates multi-input and multi-output production technology. The estimated results for allocative efficiencies offer unambiguous evidence that staple grains for food, processing, and feed are produced in excess relative to fruits and vegetables. Moreover, this tendency was particularly noticeable following the introduction of the Producer Subsidy Program in 2004. At the same time, technical efficiencies also deteriorated significantly during the period studied. These results lend strong support to the assertion that government intervention in factor markets that aims to boost grain production and thereby improve grain self-sufficiency is responsible for shifting farmers' technical choices and product mixes away from the most efficient and profitable selections.

More rigorous investigations based on household-level models are needed to gain a full understanding of farmers' decision-making processes that engender these inefficiencies. However, inefficient technical choices and unprofitable product mixes are to the detriment of farm income maximization, incurring deadweight losses for society. If China's central government views social welfare losses as costs indispensable for maintaining self-sufficiency in food staples or food security, they must seriously consider who is to bear these costs. It remains empirically unexplored to what extent the PSP subsidy payments compensate grain-growing farmers for their foregone income.[19]

There is little room for China to extend its *de minimis* subsidy measures as long as the PSP and price support programs currently underway are categorized into the "amber box" policy in the WTO agreements. Although some scholars express strong disagreement with this classification, the continuation of this type of policy has limits. The proposed "modalities" for agriculture in the Doha Round of WTO negotiations contain a formula that requires further elimina-

19) Provided that the Chinese economy keeps growing into the future, food security goals in the country will move away from food access for the poor to preparation for any contingencies. See Shogenji (2006) for a general and comprehensive discussion of food security and self-sufficiency.

tion of overall trade-distorting domestic supports and reduction of the *de minimis* levels. Even though China is exempt from further reduction commitments due to its developing country status, the current WTO agreements will continue to be the factors limiting the policy options available to the government. Northeast Asian economies, including China, share a great enthusiasm for maintaining food self-sufficiency. However, international treaties prevent them from employing interventional and protectionist policy measures; these rules instead lead producers on an irreversible path of diversification and selective expansion of farm products under the invisible guidance of market mechanisms.[20)]

Appendix: Regional Specialization of Agricultural Production

The specification coefficient of crop i for province j, SC_{ij}, is given by

$$SC_{ij}=\frac{A_{ij}/\sum_i A_{ij}}{\sum_j A_{ij}/\sum_i \sum_j A_{ij}}, \qquad (A.1)$$

where A_{ij} denotes sown areas of crop i in province j. SC_{ij} is distributed centered around 1, and the more province j specifies in producing crop i, the larger the coefficient is. The regional concentration coefficient of crop i, RC_i, defined as the aggregate value at the national level, is given by

$$RC_i=50\sum_j \left| \frac{A_{ij}}{\sum_j A_{ij}}-\frac{\sum_i A_{ij}}{\sum_i \sum_j A_{ij}} \right|. \qquad (A.2)$$

Substituting equation (A.1) into (A.2), we have

$$RC_i=\frac{50}{A}\sum_j \left(\left| SC_{ij}-1 \right| \sum_i A_{ij} \right), \qquad (A.3)$$

where A denotes the total sown areas (Muto, 1985). Equation (A.3) suggests that RC_i becomes larger as regional specification for crop i advances. Appendix Table 1 shows the computation results of equation (A.3).

Regional specification developed in the first sector during 1991–2009, while that in the second and third sectors did not. However, a close look at the computation results for individual crops provides a different perspective. The regional specification of rice attenuated during this period, while that of wheat and starchy roots progressed considerably. This may reflect the northward movement of grain production areas inside China. As for the second sector, the *RC* coefficient for maize remained almost unchanged, whereas that for soybeans rose significantly and that for oilseed crops rose modestly. The degree of regional specification of vegetables was smaller than that of fruits during the entire period. Overall, the RC coefficients of individual crops in the three sectors are smaller than those of cotton and tobacco, indicating that grain and horticultural crops are produced nationwide.

Appendix Table 1. Regional concentration of farm products

	1991	1995	2000	2005	2009
The first sector	11.0	11.4	10.4	12.6	12.9
Rice	38.7	38.8	35.6	36.3	35.9
Wheat	27.9	29.4	33.5	37.9	39.2
Starchy roots	21.5	22.5	24.9	32.2	38.5
The second sector	18.8	17.0	15.6	17.2	18.3
Maize	30.6	30.6	28.0	29.6	30.0
Soybeans	32.7	25.8	28.8	33.3	39.0
Oilseed crops	16.7	17.3	16.9	17.4	19.8
The third sector	19.6	21.5	20.8	20.1	19.8
Vegetables	17.2	17.8	18.3	18.5	18.4
Fruits	35.1	34.4	34.7	34.2	34.6
Cotton	47.7	46.2	49.7	50.3	51.0
Tobacco	35.4	44.9	41.3	45.7	47.0

Note: The author's computation is based on the CSY.

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20) China relinquished the right available to developing countries to exercise special and different treatment with respect to tariff lines and domestic support (Cheng, 2008). Faced with an increasing comparative disadvantage in agriculture, China may commit itself to establishing a new framework for international trade, instead of abiding by its WTO commitments on domestic support for agriculture.

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